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Yaw stability of a free-yawing 3-bladed downwind wind turbine

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ABSTRACT

A passive free yawing configuration can reduce complexity, maintenance costs and downtime of a wind turbine, due to the absence of an active yawing mechanism. However this concept is often unstable in yaw rotation and therefore rarely used. In this paper, a free-yawing, 3-bladed, stall-regulated, downwind medium sized wind turbine is investigated with respect to static yaw stability. Different blade coning angles under yawed inflow conditions are considered for some exploratory stability calculations, using the aeroelastic code HAWC2.

KEYWORDS

Wind turbines, yaw stability, passive yaw, coned rotor

1 INTRODUCTION AND BACKGROUND

A detailed description of a coned wind turbine rotor concept is discussed in [1] (ex. free yaw). Yaw stability of a free yawing turbine is always problematic (see for instance chapter 4.3.3.10 of [3]) and requires extensive analysis. For this paper, only the static yaw stability is considered (no yaw degree of freedom present). Note that a free yawing configuration can only be stable dynamically in yaw (see figure 1) when there is at least static stability. One of the key parameters which can influence yaw stability is blade coning angle (see figure 2).

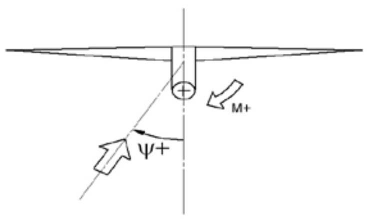

Figure 1

Static stability requirement: for positive yaw error Ψ, the yaw moment should be as indicated (positive). For a negative yaw error, the yaw moment should be negative to in this frame of reference. In the stable case, the yaw moment will realign the turbine again with the flow (Ψ to 0).

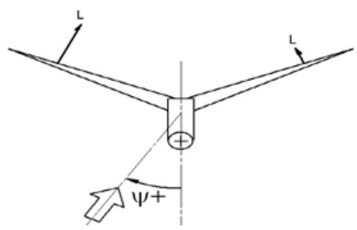

Figure 2

For a coned rotor, depending on the azimuth position, there will always be one blade which is better aligned with the flow compared to the others, resulting in different aerodynamic loading (i.e. lift). This difference in lift on the left and right part of the rotor results in a stabilizing yaw moment.

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A coned rotor can be achieved by either having a stiff blade under a constant coning angle (set at the hub), a flexible blade which deforms significantly in flap-wise direction or a combination of both. For this study, a stiff blade with a constant coning angle is considered. (as illustrated in figure 2).

2 METHODOLOGY AND SIMULATION MODEL

HAWC2 [2] is used to perform time domain simulations, using a medium sized, 3 bladed, downwind wind turbine is used (see table 1). From the steady state results of the time domain simulations, the average values over a 50 second period are considered in this paper. Both the tower and the blades have a quite stiff structural layout. The generator torque can be varied to a certain extent, resulting in a variation in rotational speed in low wind speeds. A deterministic wind field with shear (power law, exponent 0.2) and a tower shadow model is used for all simulations.

Table 1: Key parameters of the considered wind turbine model

Configuration	3 blades, downwind, stall controlled	**Cut in- cut out wind speeds**	3 – 25 m/s
Rated power	140 kW	**Rated wind speed**	12 m/s
Blade length	10 m	**Hub radius**	0.5 m
Tower Height	30 m	**Rated RPM**	57 rpm

By performing simulations for each coning angle and yaw error from cut-in to cut-out wind speed, a complete picture of the static yaw stability can be drafted. The yaw moment at the virtual yaw bearing (fixed in yaw) determines the stability: stable when yaw error and moment have the same sign (see figures 1 and 2).

In order to assess how different radial positions contribute to the yaw moment, the blade loadings at different radial positions are evaluated. They are summed up over all 3 blades and their moment contribution around the yaw bearing point is calculated. In doing so, contributions of both structural- and aerodynamic forces and moments at the blade are taken into account. This approach provides some first insight in what part of the rotor destabilizes the yawing behaviour.

3 RESULTS

3.1 Power output and flap-wise blade root bending moment as function of coning angle

Figure 3 (left) outlines the dependency of the power output on wind speed and coning angle. For especially large coning angles (larger than 20 deg), the drop in rated power is significant. The centrifugal forces have a major influence on a coned rotor. For larger coning angles, the centrifugal forces will alleviate the blade root bending moments. Theoretically, one could consider changing coning angle during operation angle that the flap-wise blade root bending moment is always close to zero. In figure 3 (right), the blade root bending moment is plotted for different wind speeds and coning angles. Note that the average blade root bending moments are affected significantly as function of coning angle.

Based on figure 3, one could intuitively say that a coning angle in the range 10-20 degrees could mean a close to zero blade root bending moment for some wind speeds while having a not too high penalty on the power output.

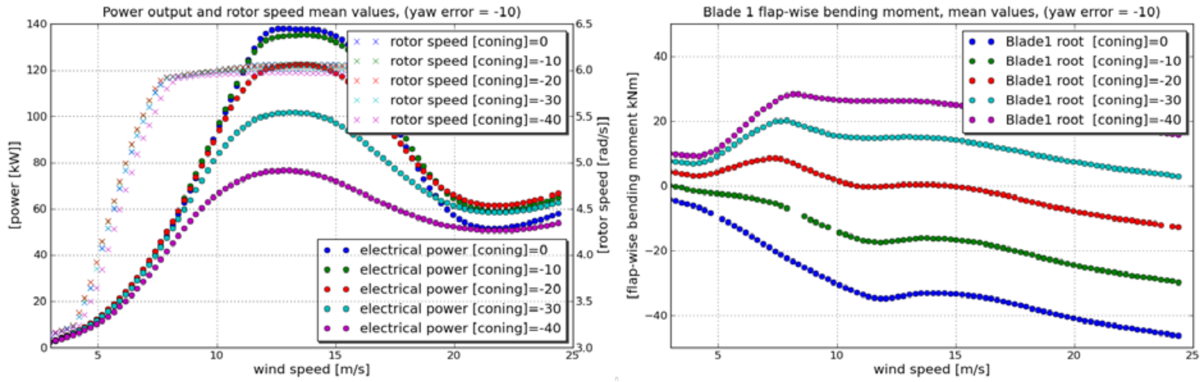

Figure 3: Power output (left) and blade root bending moments (right) as function of wind speed and coning angle

3.2 Yaw moment as function coning angle

A turbine under yawed inflow conditions behaves none symmetrically with respect to the yaw moment: wind coming from the right or left results in non symmetric loadings (see figure 4). In order to have static stability, a negative (positive) yaw error requires a negative (positive) yaw moment. From figure 4, it can be concluded that positive yaw angles are not problematic with respect to static yaw stability for a coned rotor, since at all times the yaw moment is larger than zero. For a negative yaw error on the other hand, between 11 and 16 m/s (depending on the cone angle) there exists a destabilizing yawing moment.

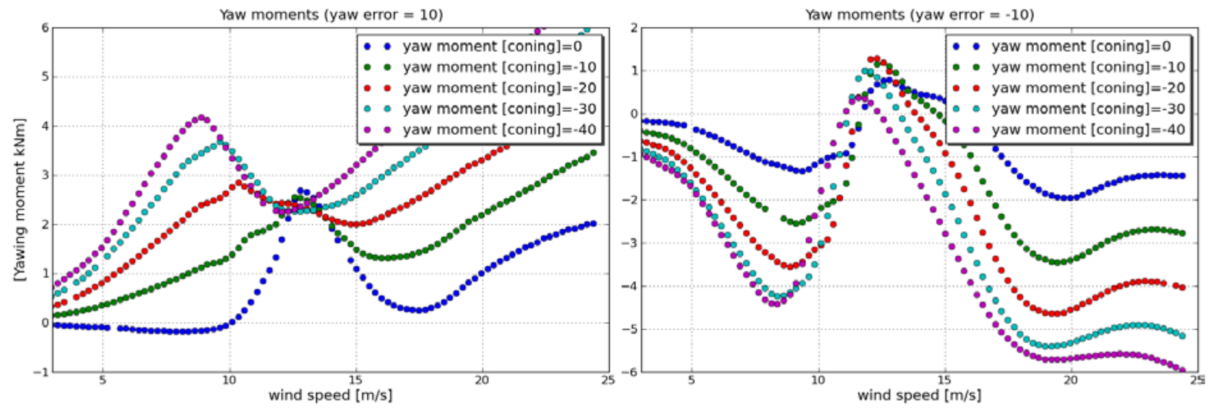

Figure 4: Yaw moment for different coning angles, while subject to a yaw error of 10 and -10 degrees. Static stability for positive (negative) yaw error when yaw moment positive (negative)

3.3 Radial blade load yawing contributions

In order to identify which airfoil sections are responsible for the unstable yaw moment contribution in the negative yaw error cases, yaw moment contributions for different radial positions of the blade are evaluated. The average yaw moment contribution of each node (considering the 3 blades) is plotted for different coning angles and wind speeds in figure 5. Especially the inner part of the blade (relative radius of 15-45%) contributes to a destabilizing yaw moment

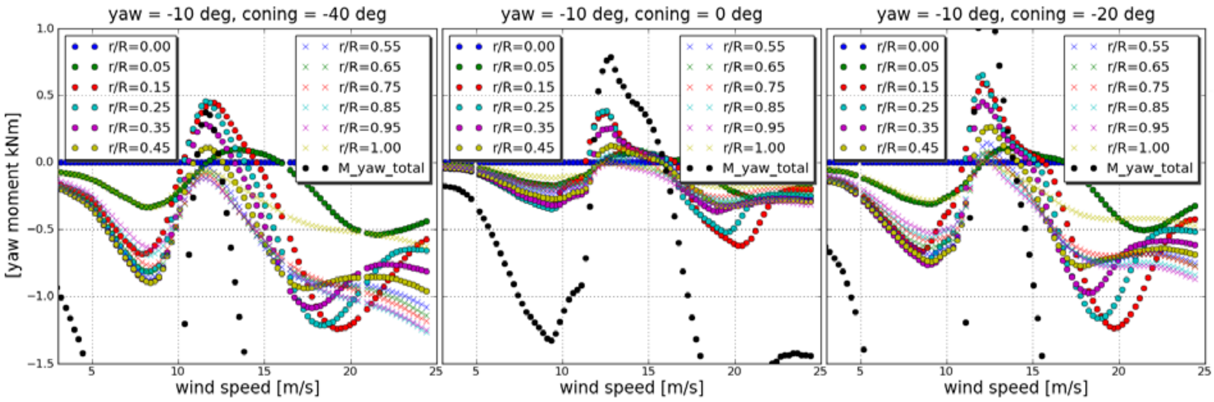

Figure 5: Yaw moment contributions per 3 blades radial positions, ranging from root to tip

4 CONCLUSIONS AND FUTURE WORK

Static yaw stability seems to be achievable for a downwind, coned rotor. However, an unstable region around 11-16 m/s (depending on coning angle) remains for negative yaw errors. The inner part of the blade is responsible for these small unstable regions and it is suggested to further investigate the influence of lift/drag contributions, airfoil selection and 3D aerodynamic correction methods on the yawing moment.

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